The Effects of Prescribed Burns on Oak (*Quercus* spp.) and Red Maple (*Acer rubrum*) Stump Sprouts in Southeastern Ohio

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ABSTRACT:

Oak (*Quercus* spp.) regeneration within Ohio's forests is a current concern for land managers. The sprouts of oak are being lost during the stem-exclusion stage of forest succession with species such as red maple (*Acer rubrum*) replacing the historically dominant oaks. Many wildlife species rely on the hard mast oak acorns to get them through the winter season, and with a reduction of overstory oak, it is probable that these wildlife species will face additional stresses.

Attempts to increase the regeneration of oak have resulted in the use of prescribed burns alone, as well as prescribed burns in conjunction with overstory thinnings. Many of the experiments examining these treatments focus on the responses of single sprouts and do not address the clusters of sprouts that form from the base of harvested stumps. Studies examining the effects of these treatments specifically on stump sprouts of oak and red maples have not been discovered by the author, with either few or no such previous studies existing. In this study, two forests were thinned with half of the harvested area being burned in the spring, and the other half burned in the fall. The differences in burn season has been shown to produce variances in fire intensities, which might have affected stump sprouts in different manners. Both the fire behavior, as well as each sprout's response to the burns were studied for this experiment.

While the expected outcome was to find a more intense fire in the fall, there was no significant difference between the spring and fall burns. Oak, both in the red and white oak species groups, were expected to have an increase in stump response, while red maple was expected to create more re-sprouts than either oak group. This was observed for the white oak species group, but the red oak group was found to respond more negatively than not only the white oak group, but also more surprisingly, the red maple sprouts. A single prescribed burn, three years after harvest, was found to benefit red maples more than anticipated, possibly suggesting that additional burns may be necessary when regeneration of stump sprouts is the land manager's goal.

INTRODUCTION

Many of Ohio's hardwood forests include oaks (*Quercus* spp.) as part of the dominant overstory, but research shows that oak saplings are being removed from the stem-exclusion stage of forest succession by what were historically less dominant species (Huang and Boerner 2008, Morrissey et al. 2008). By losing these oak saplings, forest managers are facing the possibility of a permanent loss of oak from their forest stands. This loss will have large repercussions for the ecological make up of the forests, as well as possibly impacting the economic value of the timber standing in managed forests. Oaks are important within the ecological community largely due to their hard mast acorns, which resist rot and decay longer than soft mast fruits. Many animal species are dependent on caches of acorns that they collect during the fall to last them through the harsh Ohio winters. Oak species also provide ample opportunities for roosting, nesting, and foraging within their canopies. Economically, oaks are currently almost twice as valuable as red maple, and a forest manager could face drastic financial losses if oaks do not successfully regenerate. Researchers have linked the drop-off in oak recruitment with the recent, 100-year reduction and loss of forest fires within Ohio's forests (Abrams 1992).

Historically, surface fires occurred frequently within Ohio's hardwood stands, allowing fire resistant species to develop a dominant position within the forests. Oaks have been shown to posses this resistance, while current competitors of oaks, such as maple species, do not (Bova and Dickinson 2005). Managers have attempted to reintroduce fire within their stands to encourage oak recruitment past the stem-exclusion stage, but these attempts have been met with mixed results. Additional research shows that a mixture of overstory thinnings and prescribed burns are necessary to fully encourage oak regeneration while retarding that of maple (McEwan et al. 2007). Prescribed burns have been shown to vary in intensity depending on which season they are lit, with spring burns possibly being less intense than fall burns (Schwemlein and Williams 2007). These variances in temperatures could alter how sprouts respond to the burn, and should be further examined. Research showing that oak saplings respond favorably to repeated fires has only examined the seedling sprouts. Very little has been done to examine the effects of fire on the stump sprouts created by the thinnings which are now occurring within these managed stands. To further expand the understand of how oak regeneration can be enhanced within Ohio's forests, this study has three main objectives:

1) To determine the responses of oak and red maple stump sprouts to a prescribed burn,
2) To determine if differing levels of overstory thinnings impact stump sprout responses to the prescribed burn
3) To determine if there is a significant difference in fire intensity between a fall burn compared to a spring burn,

RECENT WORK AND JUSTIFICATION

Oaks (*Quercus* spp.) are an ecological and economically important species within Ohio’s deciduous forests. The hard mast fruit produced by these species is utilized by many wildlife species for immediate consumption, as well as horded for use during winter months when food supplies are limited. Along with the production of a valuable food resource for wildlife, oak ecosystems also provide a unique habitat that some wildlife species are strongly associated with. Their bark also provides shelter for many insects, which birds and other wildlife forage upon. Oaks are an important human resource because of their use in lumber products, providing economic incentive for their harvest. By comparison, some of the shade-tolerant species that grow beneath oak canopies are not as beneficial economically or ecologically. It is because of the benefits provided by oaks that their struggle to perpetuate themselves has attracted a substantial interest and concern.

Historically, oaks were one of the dominant tree species in southern Ohio, even though they are an early to midsuccessional species. They gained and maintained their dominance through frequent, disturbances such as disease and fire. Native Americans are suspected of artificially increasing the historic fire rotation in the eastern United States based on many eyewitness accounts describing human ignited fires during the early colonization of eastern America. Once areas initially inhabited by Native Americans fell into the hands of early American settlers, intense, large scale disturbances continued through the clearing of land for agriculture and iron production (Abrams 1992). However, following a drastic change in silvicultural practices in the past 100 years limiting fires and other major disturbances, oaks are losing their dominance (Morrissey et al. 2008). Some prolific sprouters, such as red maple (*Acer rubrum*) and yellow-poplar (*Liriodendron tulipifera*) are replacing oak in the understory by out-competing oak saplings during the stem-exclusion stage (Huang and Boerner 2008). Oaks currently maintain their dominance in the overstory, but oak saplings are dropping out during the stem-exclusion stage at a higher rate than what has occurred historically. Maple (*Acer* spp.) specifically are species of concern in that they may replace oak as the dominant species within the overstory. Maples differ from oak in that they are shade-tolerant and fire intolerant, while oak is shade-intolerant and fire tolerant (Bova and Dickinson 2005). Maples' shade-tolerance allows them to establish within a shaded site more quickly than oaks. The understories of oak forests are an example of such a place where maples are able to utilize their quick establishment to dominate and outcompete oak saplings. These oak saplings fall behind in their establishment because of their shade-intolerance. In areas that are clear-cut removing the overstory and the shade that it produces, oaks are able to photosynthesize at a higher, more efficient rate than maples (Parker and Dey 2008).

Knowing that oaks photosynthesize and grow more efficiently under a removed or thinned canopy, forest managers are attempting to increase the establishment of oak by performing stand thinning in areas where oak regeneration is desired. This creates a unique opportunity to encourage the recruitment of oak not only from the seed bed, but also from the stump sprouts of harvested trees. In fact, the majority of the oak stems observed in these harvested areas are from the stumps of harvested trees. These stump sprouts can make up to 45% of the dominant oaks following harvesting in a stand (Morrisey 2008), partially due to the extended root network that stump sprouts have access to. This large resource for oak recruitment is important to study separately from seed germinants due to the differences between their growth responses. Stump sprouts' more advanced root network has a larger store of nutrients, as well as an increased ability to gather nutrients from the soil compared to that of seedlings. This allows more of the sprouts energy to be placed into vertical growth rather than in additional root growth (Rieske 2001). This difference can play a large role in the response of oaks to surface fires, with stump sprouts possibly growing more vigorously than seed sprouts.

Fire is specifically identified as the main recruiter of oaks. Correlations between historic oak recruitment and fire events have been shown (Hutchinson et al. 2005), and oaks' have a greater fire resistance compared with maples (Bova and Dickinson 2005). Oaks are able to survive fires more readily than both maples and yellow-poplars because of distinct physiological differences between the species. Oaks have thicker bark than maples of the same basal diameter, they create larger root networks than maples, and their stem collar is underground, protecting it from burns. The root collars of maple and other species such as yellow-poplar, occur just above the soil surface (Bova and Dickinson 2005, Alexander et al. 2008). These advantages allow oaks to survive fire disturbances that would reduce or eliminate their competitors, such as maples, which would otherwise replace oak sprouts in a shaded situation. It is believed that fire suppression is one of the key reasons oak regeneration has been reduced in the forest ecosystems over time. Periodic burns have historically retarded or eliminated maple and yellow-polar growth, while oaks have been able to survive burns more consistently, as well as regenerate more quickly after a burn. In southeastern Ohio, fires have been directly linked to oak recruitment, with periods without forest fires failing to show oak recruitment (Hutchinson et al. 2008). Oaks, exposed to a burn during dormancy, are more able to be biologically productive during the next year's growing season compared with oaks that have gone unburned (Rieske 2001).

It is generally agreed that the constant lack of understory disturbances from fire suppression over the past century has allowed other species to out compete oaks (Morrissey et al. 2008). Oak systems were initiated during periods of frequent fires with short time spans between burns, on average one surface fire every six years (McEwan et al. 2007). Forest managers who wish to recreate a historic fire regime within their forest frequently examine fire scars to determine how often to prescribe burns. However, this does not grant a perfectly clear understanding of how frequently fires actually occurred since not every fire will create a scar in trees. It is quite possible to underestimate the historic fire rotation since fires that burn in close succession of each other, for example, the year or two immediately following a previous fire, will be of potentially much lower intensities than the earlier fire (McEwan 2007). These reduced fire intensities result in less scaring in mature and sapling oaks. Regardless, scaring still occurs statistically often enough to be beneficial in planning fire return intervals (Smith 1999). The effects of these repeated fires can suppress fire intolerant species, such as maples, while allowing fire tolerant oaks to grow productively during the less intense fires. An example of where this growing condition has occured is near the National Guard Training Center in Fort Indiantown Gap, PA. Forests there have been exposed to repeat burnings with short return intervals due to military training exercises that occur within them. In areas with an average return interval of four years, oak saplings were abundant, while areas that had been fire free for an extended time period had little to no oak regeneration occurring within their understory (Signell 2005).

Fire alone, however, does not provide conditions necessary for successful oak recruitment (Hutchinson et al. 2005). Combining fires with overstory thinning provides conditions that allow for the strongest oak regeneration (Waldrop et al. 2008, Iverson et al. 2008, Hutchinson et al. 2008). When used alone, a prescribed burn has been shown to hinder the sprouting of maple seedlings for up to four years before seedling density returns to pre-burn levels. When a burn is paired with an overstory thinning, however, shade-tolerant species were suppressed over a considerably longer time frame (Albrecht 2005). Attempts have been made to use fire alone to open the overstory, with intense fires being made to encourage crown mortality, but the amount of opening it creates is not sufficient for oaks to become competitive (Alexander et al. 2008). It is more straightforward and direct for managers to achieve a desired level of crown opening by performing thinning through harvesting. When shelterwood treatments were applied in a study by Parker and Dey (2008), oaks responded to the greatly decreased overstory by having increased rate of respiration and water usage compared to maples. In studies using a combination of prescribed fires and mechanical thinning, oaks responded better in plots where both thinning and fire were applied, as opposed to thinning or fire exclusively (Waldrop et al. 2008, Iverson, et al. 2008). Clearcutting has also been used to completely remove any overstory for oaks to establish. When oaks occupying plots within these areas were treated with prescribed fires, they were more likely to out compete maples (Gould et al. 2007, Weigel and Peng 2002). In both clearcuts and shelterwood cuts, stump sprouts are an important source of oak regeneration due to the pre-existing root network and stored resources that the sprouts are able to utilize.

Stump sprouts are the most likely to appear from harvested or top killed trees that have smaller diameters at breast-height (DBHs). As a tree's DBH increases, the potential for stump sprouts drops, and at a certain point there is almost a zero percent chance of stump sprout production (Weigel and Peng 2002). Within oaks, chestnut oaks (*Quercus prinus*) maintain the highest probability for stump sprouts over their lifespan. Oaks in the red oak group are the next most successful, with the remaining white oak group having the lowest sprout potential of oaks. Stump sprouts can be a reliable guideline used by foresters to predict oak regeneration in an area after a timber harvest, as long as the competing sprouts that will also be occurring in the disturbed area are removed. Prescribed fires can be used to accomplish this removal of unwanted species.

Prescribed burns that have been traditionally conducted in late winter/early spring may need to be repeated two to three times over a five year period, or even annually to accomplish this goal of non-oak sprout control (Alexander et al. 2008). These repeated fires do not have a negative impact upon the vegetative cover, or even on the availability of soil nutrients for an area (Huang and Boerner 2008, Hutchinson et al. 2005). It has been shown that a burn in the fall is greater in intensity by possessing a greater flame temperature than a late winter/early spring burn (Schwemlein 2004). This difference in fire intensity between seasons could, in turn, create a different mortality or damage rate to sprouts within treated areas. Species may also respond differently to the burn season due to differences in their metabolism and other biological differences at that given point in their growth cycle (Knox and Clarke 2006). Given this, it is possible that a fall burn may create a higher mortality in non-oak stump sprouts than in oak stump sprouts in a single burn. It may not completely eliminate the need for repeated burns, but the number of burns, or the duration of time between repeat burns, may become more flexible with fall burns than spring burns.

The general consensus among researchers is that for oak establishment to occur, treatments need to combine overstory thinnings with repeated prescribed burns which occur relatively shortly after the initial thinning. Since the full effectiveness of these treatments is still being investigated, any forest manager who wishes to recruit oaks should implement this strategy as part of an adaptive management plan. Oak sprouts should be found in greater densities than shade-tolerant species after a thinning and prescribed burn. Luckily for the manager, these treatments appear as if they must occur in rather quick succession, allowing a definitive evaluation of their effectiveness within a decade or two after their implementation. If a manager performs these treatments within at least a five year period, and does not see an increase in oak recruitment, then the manager will need to attempt something else to aid oak sprouts. It is assumed that once oak seedlings and saplings become established in an understory with hindered shade-tolerant competitors, the oaks will be able to progress quickly enough to prevent their being competitively excluded. While burns are encouraged to be applied with anywhere between a four to six year rotation period early in oak regeneration, once they reach sapling size it may be possible to reduce the rotation period to once every ten to fifteen years. Again, if the manager does not see an increase in oak dominance within at least the first twenty years, then they will know that they have to re-evaluate their management techniques used in increasing oak dominance.

Managers who attempt to achieve increases in oak recruitment within their forests are not just specifically improving oak regeneration. By providing an assured, long-term oak presence in the forests, land managers are ensuring that many of the resources needed by various wildlife species are present in the forest stands as well. As mentioned earlier, hard mast acorns are vital to many species as a food source since these fruits are able to be hoarded as a reliable source of food during the winter months. Also of importance is the microhabitat provided by the oaks themselves. Their bark provides shelter for many insect species, which larger insectivores forage upon. As oak trees become older, they can also provide roosting or nesting cavities for larger species such as bats, raccoons, squirrels, or woodpeckers.

While encouraging oak regeneration counters the natural succession in many of America's forests, ecosystems with oak overstories are important to much of the eastern United States. If natural forces were allowed to progress without any interference by humans, such as those created by Native Americans as well as early European settlers, it is likely that maples would have replaced oaks as the dominant overstory tree throughout much of oak's current home range. However, since disturbances initiated by early human inhabitants maintained oaks as dominant members of the forest canopies, these are the ecosystems that modern society is familiar with on its landscape. Arguments can be made about whether or not it is natural to maintain oak dominance within the ecosystem by applying disturbance treatments known to encourage oak survival. It may not be exactly as nature intended, but the forests that will replace oaks without managerial intervention may not be able to provide the same ecological and economical resources that current oak stands possess. Forest managers must make that decision for themselves, since many of the ecosystem services provided by oak forests have been intertwined with the communities that surround these stands. Altering the historic forest resources may therefore have serious repercussions among these surrounding communities.

METHODS

The mixed hardwood forests of Richland and Zaleski SF, in southeastern Ohio, were used as the study area locations. Lying in the unglaciated portion of Ohio, their topography is characterized by an undulating terrain created by watershed drainage ravines. Both these forests had a recorded dominance of oaks, with 87% of the basal area in Zaleski SF and 84% of the basal area in Richland Furnance SF consisting of oaks. As part of a pre-exisiting research project four, 10-hectare treatment areas were established in each forest for a total of eight treatment areas. Two of these areas per forest were harvested with a 70% retention rate with the remaining two being harvested with a 50% retention rate (Table 1), with all harvesting occurring in 2005. It was from these harvests that the stump sprouts to be measured were created. The over-harvesting of Zaleski SF's 70% retention plots prevented this study from examining effects of differing overstory densities on the stump sprouts.

Table 1. The mean forest overstory attributes before and after shelterwood harvest treatments (reduce to 70% stocking and 50% stocking) in Richland Furnace and Zaleski SFs in southern Ohio.

Harvest period	State Forest	Treat.	Basal area (m^2/hectare)		Trees per hectare		Dbh (cm.)		Stocking (%)	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD
Before	Richland Furnace	50%	25.5	6.3	272	67	30.6	3.7	88	21
		70%	26.2	5.0	351	68	30.7	2.9	93	17
	Zaleski	50%	24.4	4.3	315	70	28.2	3.2	86	14
		70%	23.6	7.1	342	104	26.2	3.3	84	24
Post	Richland Furnace	50%	13.7	4.2	57	17	52.4	8.3	45	14
		70%	18.0	4.7	129	33	41.1	4.5	61	15
	Zaleski	50%	15.4	4.3	115	33	40.2	6.4	52	14
		70%	14.0	7.1	105	47	39.5	5.0	47	24

In each treatment area, eight circular, 0.08ha research plots were established, for a total number of 64 plots. At each plot, a red oak species group member (*Quercus rubra, Quercus velutina,* or *Quercus coccinea)*, white oak species group member (*Quercus alba,* or *Quercus prinus*), and red maple (*Acer rubrum*) stump sprout cluster were chosen to be measured and followed for the duration of the experiment, for a possible maximum of 192 stumps. The total number of sprouts from each stump were recorded, and from each of these clusters, a random sprout was selected. This sprout's height and DBH were recorded, and an aluminum tag was placed around the sprout so that it could be found again for future re-measurements.

After every sprout was measured, prescribed burns were conducted within the treatment areas. Both a 50% and 70% retention treatment area were burned, per forest, in the fall of 2009, with the remaining two areas being burned in the spring of 2010. During both of these burns, heat-sensitive paint tags were placed at the base of each, previously marked, stump sprout. Each aluminum tag was painted with ten heat sensitive paints that melted at 175, 200, 250, 300, 350, 400, 500, 600, 800, and 1000 degrees Fahrenheit respectively. Around each painted tag, a thin layer of aluminum foil was wrapped to protect the paint before and after the burns. These tags were then placed on a steel wire at 0, 20, and 40 cm from the surface of the soil. Once collected after each burn, the paint tags were used to estimate the temperatures of the fire at the base of each sprout by using the last paint to melt as the maximum temperature reached (e.g. if the 300ºF paint melted at 40cm, the fire was said to be 300ºF at that height). After both burns were conducted, the full growing season in 2010 was allowed to occur before the final measurements for all stump sprouts were collected. These final measurements included identifying if the original sprouts were unharmed, damaged, or killed (top killed or entirely killed) by the fire. The number of new, post-burn sprouts were counted, with a random sprout from these new clusters chosen to have its height and DBH measured. Pre- and post-burn sprouts were determined by the presence of fire damage, with the new sprouts having all of their buds intact and possessing no charring or other obvious fire-induced characteristics. Some of the original stump sprout clusters were lost due to deer removing the marking tags between the initial and re-measurements. These stumps that could not be measured after the growing season were dropped from the study, which resulted in a total of two stumps being lost from the sample group.

Once all of the data was collected, analyses of variance (ANOVAs) were conducted with significant p-values being those at or below 0.05. The average flame temperatures of the fall and spring burns were compared using an ANOVA, as were the average temperatures, by species, that each stump sprout was exposed to. The average number of original sprouts, and their average DBHs were compared to the average number of post-burn sprouts and the average DBH within species groups by ANOVA. These post-burn sprouts also had their average DBH's, and average numbers compared among species with an ANOVA to determine if there was a significant difference between species. As mentioned earlier, the thinning treatments varied too much from the desired stocking levels, preventing any data analysis using these values.

RESULTS

The mean temperatures for the fall burn (559.42°F, sd 156.72) was greater than the spring burn (540.84°F, sd 111.76), but this variance was not significantly different (P>0.05 Table 2). Mean temperatures at the base of each species group, however, were found to be significantly different among the species groups. The red oak group was exposed to a significantly (P-value 0.028) higher mean average temperature than the white oak group or red maples. For both red oaks and red maples, these temperatures were significantly impacted by the mean slope bearing of the sprouts, south, and red maple's mean temperature was also linked to their mean middle slope postioning (Table 3). The average temperature for both fall and spring combined was 550.96°F, with a standard deviation of 137.80. There were some tags though which were outliers in that their recorded temperatures were over 1000°F. Some of these aluminum tags became so hot that they melted off of the steel wires and were found on the ground in a small ball. These tags, as well as tags found on poles that had bent over from excessive heat, were excluded from the data since the temperatures had exceeded the measurement capability of the equipment. This deduction resulted in the loss of nine stump sprouts from the sample group.

Table 2. The mean flame temperatures by season, and the difference between them, in Richland and Zaleski SFs in southern Ohio.

State Forest	Burn season	Sample size	Mean Temperature (^oF)	Standard deviation
Richland Furnace	Fall	30	582.22	129.41
	Spring	29	552.30	109.54
Zaleski	Fall	31	537.07	144.40
	Spring	22	527.08	168.60

Table 3. The mean temperatures at the base of each species group in Richland and Zaleski SFs in southern Ohio.

Species	N	Mean[1] temperature (^oF)	Standard deviation	Mean aspect (degrees)	P-value	Mean slope position	P-value
Red oak	56	594.20a	141.57	S (185)	0.021	Middle	0.241
White oak	33	572.22ab	142.37	SW (224)	0.524	Middle	0.892
Red maple	23	520.68b	128.57	SW (216)	0.023	Middle	0.066

[1]Means followed by the same letter are not significantly different at P<0.05

Of the total possible 192 stump sprouts, only 112 sprouts were found with 23 stumps in the red oak group, 33 in the white oak group, and 56 red maple stumps. Differences in numbers resulted from the lack of some species occurring within every plot. The change in the mean number of sprouts for each species was found to change significantly from before the prescribed burns compared to after the prescribed burns (Table 4). The initial mean numbers of stump sprouts for each species group were found to not be significantly different, while the mean numbers of stump sprouts after the prescribed burns were found to have some significant differences. Sprouts in the red oak group were reduced from an initial mean of 5.19 sprouts per stump, to 4.81 sprouts per stump, which was not significantly (P-value 0.285) different than the white oak group's post-burn 5.70 sprouts per stump, but it was found to be significantly different (P-value 0.047) than the red maple's post-burn 6.39 sprouts per stump (Table 5). All measured sprouts were top-killed by the burns, and the re-sprouts' heights and DBHs were compared to the initial sprouts' measurements (Table 6, Table 7). The mean DBHs were compared by species, with red oak having the largest decrease in DBH. All species experienced an increase in sprout height following the burns. The differences between the initial sprout heights and re-sprouts' heights were found to be significant (P < 0.001). Red maples experienced the largest increase in mean sprout height (11.1ft), while red oaks had the least increase in height (7.5ft). The mean height of white oak increased by 9.5ft.

Table 4. The mean[1] number of pre-burn stump sprouts compared to the number of post-burn stump sprouts in Richland and Zaleski SFs in southern Ohio

Species	Mean number of pre-burn sprouts	Standard deviation	Mean number of post-burn sprouts	Standard deviation	P-value
Red oak	5.19 a	2.93	4.81	2.48	0.0460
White oak	5.18 a	2.52	5.69	2.53	<0.0003
Red maple	5.67 a	2.47	6.39	3.23	<0.0001

[1] Means followed by same letter are not significantly different at p<0.05

Table 5. The mean[1] number of post-burn stump sprouts for each species group in Richland and Zaleski SFs in southern Ohio

Species	Mean	Standard deviation	Minimum value	Maximum value
Red oak	4.81 a	2.48	0	11
White oak	5.70 ab	2.53	1	10
Red maple	6.39 b	3.23	0	13

[1] Means followed by same letter are not significantly different at p<0.05

Table 6. The mean[1] dbh, by species, pre and post burn in Richland and Zaleski SFs in southern Ohio.

Species	Sample size	Pre-burn Mean dbh	Pre-burn Standard deviation	Post-burn Mean dbh	Post-burn Standard deviation
		mm			
Red oak	23	17.61 Aa	6.15	6.54 Aa	3.17
White oak	33	16.52 Aa	8.04	9.75 Aa	6.50
Red maple	56	14.48 Aa	6.76	6.67 Ba	2.86

[1] Means followed by same capital letter are not significantly different between pre-burn and post-burn within species ($p = 0.05$). Means followed by same small case letter are not significantly different between species within pre-burn and within post-burn periods ($p=0.05$).

Table 7. The mean heights, by species, of the stump sprouts before and after a prescribed burn in Richland and Zaleski SFs.

Species	Sample size	Initial height Mean	Initial height Standard deviation	Re-sprout height Mean	Re-sprout height Standard deviation
		ft.			
Red oak	23	8.2	0.61	15.7	1.38
White oak	33	8.5	0.77	18.0	2.34
Red maple	56	8.9	0.80	20.0	1.85

DISCUSSION

The burn temperatures were expected to show a similar trend as was found in Schwemlein and Williams (2007), where the spring burn was less intense with significantly lower temperatures than those found in the fall burn. It was presumed that burns occurring in the spring were less intense due to the compaction of fuel by the previous winter's snow falls. This compaction would limit the amount of airflow available within the fuel to feed the flames of a burn, preventing the fire from reaching temperatures comparable to a burn in the fall, where newly fallen leaves and other materials have gaps and spacing within their arrangement to allow for large amounts of airflow to feed the flames. However, in this study, five of the nine sprouts which were removed due to temperatures too extreme to accurately measure, occurred during the spring burn. In fact, two aluminum tags from the spring burn at Richland Furnace SF melted into balls. However, it is important to note that during the burn at this forest, fire igniting procedures were delayed by an hour and a half to two hours due to a water tank falling from the bed of a tanker. It is possible that this change in ignition time from late morning (approximately 11AM) to early afternoon (approximately 1:30PM), allowed for the removal of more moisture from the fuels due to the increased temperatures experienced later in the day. This may have brought larger fuels into play than just the expected 1-hour fuels. It would have been beneficial to this study if a comparison of the prescribed fuel moistures with the actual fuel moistures at the time of ignition had been conducted. The sample base was also strongly biased towards southern facing slopes, with 52.6% of the heat tags placed on western, southwestern, or southern facing slopes, while only 14% of the tags were placed on northern, northeastern, or eastern slopes. Since fires in the northern hemisphere tend to have higher intensities on south and southwestern slopes, this could have impacted the comparison of fire temperatures because the more extreme temperatures within each burn were observed. By having a lack of data for the lower intensity, northern slopes, the less intense portions of the fire may not have been observed.

The most surprising result from this study was the response of the red oak group's stump sprouts to the prescribed burns. While both the white oak group and red maple, increased their numbers of stump sprouts (Table 4), oaks in the red oak group actually had a decreased number of sprouts. Knowing about oaks' (*Quercus* spp.) fire tolerance, sprouts in both the red and white oak groups were expected to respond favorably or without a loss in overall fitness. The comparisons among species indicated that the red oak group was more negatively impacted by fire than other groups (Table 6, Table 7). Red oak not only had a reduction in stump sprout numbers (5.19 pre-burn compared to 4.81 post-burn), but also the largest reduction in mean DBH, with a 63% decrease compared to white oak (41% decrease) and red maple (54% decrease). Red oak re-sprouts responded with the least increase in vertical growth (7.5ft) compared to white oak (9.5ft) and red maple (11.1ft). This reduction in sprout response could be due to the larger mean DBH of red oaks (17.61mm) compared to white oak and red maple due to the tendency for re-sprouting to decrease as the DBH of the previous sprout increases (Weigel and Peng 2002). Compared to other studies that show oak's ability to respond positively to prescribed burns (Alexander et al. 2008), the red oaks in this study were damaged to a greater extent than were white oaks or even, more surprisingly, red maples. A possible reason for this observed difference may be that red oak was exposed to higher fire temperatures than the other species (Table 3). The severity of the temperatures follows the same pattern as the number of re-sprouts post-burn, with red oaks being significantly different than red maples, while the white oak group temperatures are not significantly different than the red oak group or red maples. This range in temperatures is due to the random nature of fire, and to the impossibility to control factors as definitively as in a laboratory setting. Had there been more numbers of samples for both the white and red oak groups, the means for temperatures at each sprout, as well as the mean DBH and mean number of re-sprouts, may have resulted in different findings. Red oaks were the least represented group in the sample with only 23 of the total 112 sprouts. ANOVA results may also have changed had there been a larger sample size for the red oak group, as this statistical analysis considers not only the values observed, but also the number of observations.

CONCLUSIONS

These findings suggest that a prescribed burn four years after harvesting a oak hardwood stand in southeastern Ohio results in a more favorable stump sprout response from red maples compared to the response of red or white oak stump sprouts. This difference is contrary to other studies that have shown oaks to respond as well, if not better than red maples from a prescribed burn (Parker and Dey 2008, Hutchinson et al. 2005). This would be counter-productive to the desired goal of hindering the sprouts of red maple, while only slightly damaging the oak sprouts. Other studies suggest that more than one burn is required before the true benefits of fire can become apparent in the establishment of oaks over maples (Signell et al. 2005, Brose et al. 1999), which may be what is needed in these forests. It is known that red maples are prolific sprouters (Albrecht and McCarthy 2006), and their stump sprouts may simply need to be hit more than once by a prescribed burn before they are knocked back sufficiently enough to allow for oaks to dominate them. While this study was limited by a short time-frame, measurements of the sprouts should be conducted for the next four to five years, with the possibility of using another prescribed burn during this period before any final conclusions on the responses of oak and red maple stump sprouts can be made.

While the fall burn had a greater mean temperature than the spring burn, this difference was found to have not be significant. This would suggest that it does not matter when a forest manager conducts a prescribed burn, so long as the desired weather conditions and moisture contents are available. However, the temperatures from both burns (fall 559.42ºF, and spring 540.84ºF) could be high enough to negatively impact the re-sprouting of red oaks after the treatment. In Schwemlein and Williams (2007) the fall burn was found to produce significantly greater temperatures than the spring burn. The disproportionate sampling of south face slopes compared to northern facing slopes (52.6% southern, 14% northern) likely influenced this finding. Further studies should be sure to create a more equal sampling of all slopes, so that any variances between fall and spring burns can be made more clearly.

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